Project Longshot - Final Report:

Analysis of Ground Motion and
Containment, Safety Program

May 6, 1966

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ABSTRACT

Predictions of ground motions and containment were made for the Longshot event.

Limits on the areas expected to be within the radius of potential damage (acceleration $0.1g$) and perceptible motion (acceleration $0.001g$) were given. Also, prediction graphs were presented for obtaining peak particle acceleration, displacement and velocity for points of interest on Hardrock and unconsolidated material.

A preliminary feasibility study was performed to determine the acceptability of the proposed Longshot site from the standpoint of containment and seismic safety. The results of the investigation showed the proposed Longshot event could be successfully executed at the selected location. Subsequently, an exploratory drilling program was performed and a stemming plan was developed. Based upon the findings of the exploratory program and the evaluation of the stemming plan, Beers, Inc. concluded that the event would be contained at the proposed location.

Upon detonation, containment was achieved as predicted. No reports of damage or ill-effects due to excessive motions were made. A limited comparison with published ground motion data indicates satisfactory predictions.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Roland F. Beers, Inc., under Contract No. AT(29-2)-1133 with Nevada Operations Office (NVOO), U. S. Atomic Energy Commission (AEC), is responsible to the Operational Safety Division of that office for the following:

- a) Prediction of ground motions
- b) Evaluation of containment of underground nuclear explosions

Project Longshot, a contained underground nuclear test in the 80 - 100 kt range, was located on Amchitka Island of the Aleutian Chain. The device was detonated in andesite, slightly below a contact between the andesite and the overlying bedded clastics. This event presented special prediction problems due to the absence of directly applicable experience and its location off the Nevada Test Site.

Ground motion resulting from underground testing of nuclear devices is a substantial as well as a continuing operational safety problem. Current methods of predicting ground motion employ empirical relationships derived

from observed data. Proper use of these relationships for prediction purposes requires that the test conditions for which predictions are to be made be comparable with those which provided the data used in deriving the relationships.

Scaling of ground motion for yield and distance are fundamental steps in making predictions. To perform such scaling, the variation in amplitude with yield and distance must be defined. Appreciable departure in yield, source geometry, method of emplacement, and physical properties of the transmission path from previous experiments substantially affect the manner of scaling and the agreement between predicted and observed ground motions.

The possibility of a containment failure is a problem for essentially every event. This hazard becomes particularly important when an off-site event is considered. In analyzing the Longshot event, previous events, such as Logan, Hardhat and Shoal, in similar media, provided the basis for predictions of phenomenology. Where conditions were dissimilar, theoretical analyses and extrapolation of experience from other media were employed.

1.2 OBJECTIVES

The objectives of Roland F. Beers, Inc. participation in seismic aspects of the Longshot event were to provide Operational Safety Division with predictions of anticipated ground motion; more specifically, to predict the area expected within the radius of potential damage (acceleration 0.1 g) and the area within the radius of perceptible motion (acceleration 0.001 g).

The purpose of containment studies was to provide the Operational Safety Division with an independent evaluation of the probability of containment and the adequacy of the stemming plan. In performing this function, dependence was placed on theoretical considerations and on empirical data collected in large measure by others.

1.3 THEORY

1.3.1 Seismic Effects

Prediction equations for ground motions resulting from nuclear detonations have been developed by analyzing data from many of the previously conducted nuclear events. The empirical data from events in similar geologic environments were grouped; and equations relating peak motion,

yield, and distance were derived for each of the various environments. When predictions are required for events in new geologic conditions, the empirical procedure for predicting peak motions involves comparison of the physical properties of the new shot media with the properties of geologic formations for which ground motion data have been obtained and equations derived. Prediction equations for the conditions most similar to the conditions near the event in question are utilized.

Longshot was located on Amchitka Island of the Aleutian Chain, in virgin territory as far as nuclear detonation experience is concerned. The device was located slightly below a contact between andesite and overlying volcanic clastics. Based on the results of an exploration program, it was established that the andesite has physical properties resembling granite, whereas the overlying clastics resemble more closely the tuffs of the Nevada Test Site. Therefore, ground motion prediction equations derived from the results of events in the tuffs of Rainier Mesa and the past events in granite provided a basis for the Longshot predictions.

A significant qualification of the predictions concerned the possibility of generating very long period

surface waves. However, as no adequate empirical data on this type of wave were available, their motions could not be predicted. Therefore, it was believed that at long distances, peak particle motions, especially displacement, could have possibly exceeded those predicted.

1.3.2 Phenomenology and Containment

The evaluation of containment of the Longshot event was based on procedures developed as part of a long-range program directed to the continuing improvement of confidence in predictions.

Currently, great dependence is placed on empirical relationships, and it is probable that experience will always be a major factor in evaluation. However, a large part of the improvement will come from greater knowledge of the pressure-time history and temperature-time history of underground explosions.

CHAPTER 2

PREDICTIONS

2.1 ENVIRONMENT

2.1.1 Location, Topography and Culture

Amchitka is the northernmost island of the Rat Island Group, located near the western end of the Aleutian Chain. The island is about 35 miles long and 3 to 5 miles wide with a maximum elevation of about 1100 + feet. Several peaks exceed 1100 feet in the rugged northwestern part. To the southeast the topography grades into a low-lying plateau about 200 feet above sea-level.

Numerous rain-fed lakes and ponds occur on the porous but impermeable tundra. Vegetation consists predominantly of mosses and grasses on this treeless arctic island.

Amchitka island is uninhabited. The closest permanent settlement is about 190 miles to the east. Fish and wildlife, including sea otter and migratory fowl, are prevalent on and about Amchitka Island.

2.1.2 Geology

Amchitka Island is considered to be part of a great fault block of the Aleutian Ridge, which is tilted southwestward, towards the Aleutian Trench (Reference 1).

TABLE 1: PHYSICAL PROPERTIES OF SOME ROCKS FROM AMCHITKA ISLAND, ALASKA AND OTHER TEST MEDIA

Type Medium	Density (g/cc)	Porosity (%)	Moisture (%)	Poisson's Ratio	Comp. Strgth. (psi)	Mod. Elas. (Young's) (psi x 10 ⁰)	Sonic Vel. (ft/sec)
Andesite* (See Fig.1)	2.59	11.0	3.12	.24	12,000	4.95	14,300 ^(a)
Clastics*	2.27	22.2	7.07	.17	4,700	1.94	10,500 ^(a)
Climax Granite	2.67 (d)	4.0 (b)	.2-1.7 (q)	.30 (c)	18,475 (c)	11.5 (c)	18,628 ^(b)
Shoal Granite	2.58 (e,f)	<5.0 (p)	<5.0 (p)	.268 (e)	15,960 (f)	7.87 (e,f)	17,400 (e,f)
Rainier Mesa Tuff	2.0 (h)	24.4+7 (h)	14.0 (m)	.14 (j)	4,700 (h)	.98(i) to 1.46(j)	7,133 (g)
Yucca Flat Tuff	1.92 (l,m)	28.2 (n)	15.9 (i)	.15 (k)	4,700 (n)	1.11 (g)	7,600 (o)

- (a) Schlumberger Sonic Log, EH-5, Run #1, Amchitka, Alaska
 (b) Tech. Ltr: Area 15-1
 (c) Tech. Ltr: Area 15-2
 (d) TEM - 836-C
 (e) LRL Memo - Christensen to Higgins, June 11, 1963
 (f) WES Memo - Polatty to Casey, Feb. 5, 1963
 (g) TEI-355
 (h) Underground Nuclear Detonations; Journ. Geophy. Res., v. 64, #10

- (i) Tech. Ltr: Area 12-4
 (j) TEI - 797
 (k) Tech. Ltr: NTS-45C
 (l) TEM - 998
 (m) UCRL - 5542, Rev.
 (n) Tech. Ltr: NTS-45A
 (o) Tech. Ltr: NTS-45B
 (p) Estimated
 (q) UCRL - 6962

* All properties averaged from Report of Tests on Rock Core Samples, Longshot Project, Alaska; Corps of Engrs., U. S. Army, 19 Nov. 1964, (unless otherwise referenced).

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References:

- (1) Preliminary drill log, EH-5, Corps of Engrs.
- (2) Longshot Project, Alaska; Report of tests on rock core samples - Corps of Engineers, 19 Nov. '64.

CLASTICS(1,2)

Material consists mostly of pyroclastic ejectamenta. Rock types include breccia and coarse to fine grained lapilli tuff interbedded with silty and shaly mudstones and fine, sandy tuff intermediate between pyroclastic tuff and sandstone with mostly sand through clay sizes.

ANDESITE(1,2) (basalt)(2)

Upper is dense and predominantly non-vesicular to finely vesicular. Lower is slightly vesicular to vesicular and has distinct diktytaxitic texture (irregular and open cavities or voids).

GENERALIZED LITHOLOGIC
SECTION AT EH-5
AMCHITKA, ALASKA

SCALE 1" = 200'

ROLAND F. BEERS, INC.
ALEXANDRIA, VIRGINIA
DECEMBER 10, 1964

2.2 PHENOMENOLOGY AND CONTAINMENT

2.2.1 Maximum Predicted Cavity Radius

On the basis of the stratigraphic section given in Figure 1, the W.P. for the Longshot event was located in andesite approximately 20 feet below the contact with the overlying clastics. From the physical property data given in Table 1, it can be seen that andesite appears most comparable to granite whereas the clastics are better approximated by tuff properties. For a given yield, granite and tuff media will produce different cavity radii and it was thus anticipated that the Longshot cavity would be eccentric. (DELETED)

Cavities in Area 12 tuff, NTS, could be adequately predicted using the empirically derived equation $R = 54.21 W^{1/3}$. Similar data from two events in granite indicate an equation of $R = 35.53 W^{1/3}$. Utilizing these equations, two cavity radii for Longshot were computed.

$$\text{upward } R = 54.21 (100)^{1/3} = 252 \text{ feet}$$

$$\text{downward } R = 35.53 (100)^{1/3} = 165 \text{ feet}$$

The upward radius of 252 feet was considered to represent a maximum possible radius since the clastics at the Longshot site were slightly denser, less porous, compressively

stronger, and of lower moisture content than the Rainier tuff. These factors would tend to reduce the anticipated cavity radius.

2.2.2 Chimney Height

Since the physical properties of the material above the shot point approximated those for Area 12 tuff, a computation of the anticipated chimney height was based on experience in that medium. An equation was derived by the procedure described in Appendix A, Reference 3 to determine the collapse chimney height above a cavity of different upper and lower hemisphere radii. The height above the shot point (H) is given by

$$H = \frac{(n) \frac{2}{3} (R_2)^3 + \frac{2}{3} (R_1)^3}{(n-1) (R_2)^2}$$

where

(n) is the swell factor

(R₁) is the radius of the lower hemisphere

(R₂) is the radius of the upper hemisphere

The radius of the upper hemisphere was assumed to control the radius of the collapse chimney. The value of n = 1.32 was determined by averaging post-shot data from the Logan, Antler, Rainier, Platte, and Chena events. Utilizing this

in the above equation, the chimney height was predicted to be

$$H = \frac{(1.32) (2/3) (252)^3 + (2/3) (165)^3}{(.32) (252)^2} = 840 \text{ feet.}$$

2.2.3 Cracking Radius

Predictions of maximum fracturing radius were based on the maximum predicted cavity radius and the allowable strain for the medium. As shown previously, the cavity was anticipated to be asymmetric with an upward maximum radius of 252 feet and a downward maximum radius of 165 feet. The strain at failure in uniaxial compression for the clastics and underlying andesite was found to be .213% and .36%, respectively. These data were obtained from Reference 4, from which only one value could be obtained for the andesite, whereas the allowable strain for the clastics was obtained by averaging the results of six tests.

The predicted displacements, and associated radial strain, in both upward and downward directions, are shown graphically in Figure 2. From this figure it was found that a strain of .213% should occur at an upward radius of 1,800 feet and a strain of .36% at a downward radius of 950 feet. These were taken as the limits of anticipated fracturing.

Figure 2. Predicted Permanent Radial Displacement and Radial Strain
Longshot Event

2.2.4 Radius of Radioactive Injection into Cracks

The only experience available to determine the outer limit of radioactivity in a tuffaceous-like material is the Rainier event. The outer limit of radioactivity at Rainier was about 190 feet with an outer limit of cracking of 280 feet (Reference 5). Assuming that the ratio of the radius of radioactivity to the radius of cracking would be similar for Rainier and Longshot, the outer limit of radioactivity for Longshot was predicted to be

$$\frac{190}{280} \times 1,800 = 1,220 \text{ feet upward}$$

$$\frac{190}{280} \times 950 = 645 \text{ feet downward}$$

2.2.5 Depth of Spall

Two procedures were employed to obtain an estimate of the free-field pressure at surface zero. Hydrodynamic calculations indicated a pressure of 24 bars. Scaling from data produced a particle velocity of 3.24 ft/sec (Reference 8). This corresponds to a pressure of 36 bars using a conversion factor of 1 ft/sec = 11.1 bars. Both procedures assumed that tuff data was applicable to the volcanic clastics of the Longshot site.

An estimated pressure of 35 bars (500 psi) was used in spalling calculations. Using the ballistic equation, a surface displacement of 7.4 inches was obtained for the free-field particle velocity of $\frac{35 \text{ bars}}{11.1 \text{ bars}} = 3.15 \text{ ft/sec}$. Graphical analysis of spalling (as described in Appendix A, Reference 3) indicated that the net tension near the surface would be very low and the probability of major spalling was not great. If spalling did occur, it should not have extended below 100 meters or 328 feet.

2.2.6 Evaluation of Geologic Hazards

The fundamental geologic aspects of most concern to containment were the character and orientation of steeply-dipping faults which might have provided continuous avenues of existing or potential significant permeability.

All available lithologic and geophysical logs of all six exploratory holes were closely analyzed on this account. It was concluded that none of the faults intersected by the drill holes represented a containment hazard.

2.2.7 Analysis of Stemming

The stemming plan for the Longshot emplacement hole appears on Figure 3. The stemming for the emplacement

Figure 3

hole consisted mainly of coarse sand with nine plugs of fine sand mixed with bentonite. These plugs were ten feet thick and spaced approximately ninety feet apart in the drill hole. In addition, two cement plugs were employed: One of the expanding type, set at a depth of 690 feet, and the other at a depth of about 30 feet. One additional plug of expanding plastic was employed in the top 10 feet of the hole.

The stemming design was essentially the same as that considered to be normal for LASL shots at the Nevada Test Site. This design has been used successfully on many past events. The incorporation of the expanding cement plugs was an added safety feature. At a depth of 690 feet (1615 feet above the W.P.) the plugs were located about 775 feet above the predicted top of the collapse chimney (predicted: a height of 840 feet). The purpose was to resist any tendency for the stemming to drain from the hole into the chimney.

Based on this review, the stemming plan for the Longshot event was considered adequate.

2.2.8 Conclusions

On the basis of all information received, Beers, Inc. was of the opinion that the Longshot event would be safely contained at the proposed location.

Assuming a maximum yield of 100 kt at 2,300 feet, scaled depth of burial is $495 \text{ ft/kt}^{1/3}$. A comparable contained shot in similar media was Logan (5.0 kt) at a scaled depth of $485 \text{ ft/kt}^{1/3}$ under Rainier Mesa. Scaled depths of burial for Hardhat and Shoal were 520 $\text{ft/kt}^{1/3}$ and 517 $\text{ft/kt}^{1/3}$, respectively. No events in any geologic environment have vented at similar scaled depths other than through man-made openings.

The thickness of relatively undisturbed rock above the predicted Longshot chimney was estimated to be more than 1,130 feet, which represents a conservative safety margin. The chimney height was estimated to be about 840 feet and maximum depth of spall, about 330 feet.

According to the USGS (Reference 6), the drilling program as completed adequately provided a representative picture of the meaningful geologic character of the proposed site. After close analysis of data it was agreed with the USGS that no evidence existed for the presence of zones of significant permeability which could extend directly to the surface.

Essentially the same stemming plan (Figure 3) has been used successfully on many past events and has been termed normal for previous LASL shots at the Nevada Test Site. Consequently, no venting through inadequate stemming was anticipated.

2.3 SEISMIC EFFECTS

2.3.1 Ground Motion

To adequately evaluate the ground motion expected from an underground nuclear event, it is necessary to consider the geologic conditions at the source, the mode of wave transmitted, and the conditions at designated points on the surface. At a depth of 2,300 feet the device was slightly below a contact between andesite and overlying clastics-- an interbedded mixture of tuff, breccia, and graywacke (See Figure 1). The andesite has physical properties closely resembling granite while the clastics above the shot more closely resemble the tuffs at NTS (See Table 1). Although the surface is covered with a thin layer of peat, glacial till and occasionally alluvium, no large area of thick unconsolidated material of Yucca Flat dimensions is present. Some amplification of peak motion might occur locally where pockets of unconsolidated material

are present. Under these conditions, ground motion prediction equations previously used for shots in tuff and granite in Nevada were believed to provide an adequate basis for the Longshot predictions. Two sets of equations were used: One for points of observation on hardrock outcrops and the other where unconsolidated material was present on the surface.

For Location on Hardrock

$$a = 5.03 \times 10^5 W^{.7} R^{-2.0} \quad (1)$$

$$d = 1.51 \times 10^5 W^{.75} R^{-1.73} \quad (2)$$

$$u = 8.64 \times 10^6 W^{.73} R^{-1.87} \quad (3)$$

For Locations on Unconsolidated Material

$$a = 1.06 \times 10^6 W^{.7} R^{-2.0} \quad (4)$$

$$d = 5.59 \times 10^5 W^{.75} R^{-1.73} \quad (5)$$

$$u = 2.94 \times 10^7 W^{.73} R^{-1.87} \quad (6)$$

where for all equations

a = Peak surface particle acceleration in g

d = Peak surface particle displacement in cm

u = Peak surface particle velocity in cm/sec

W = Yield in kt

R = Distance in meters

Equations 1 through 3 were derived from empirical data for shots in tuff at Rainier Mesa and were successfully used

to predict motions measured on hardrock for the Fore, Klickitat and Turf events in tuff. These equations were also used to predict motions from the Shoal event in granite. The acceleration and displacement equations (Equations 1 and 2 above) agree very well with Shoal empirical data, but the particle velocity equation (Equation 2) resulted in predictions higher than observed at Shoal by a factor of about 1.6. For a normal shot in granite, Equation 2 would be reduced by a factor of 1.6. However, since the device was to be located very near a contact between materials with physical properties similar to tuff above the shot and granite below, Equation 2 was used in order to provide a more conservative prediction.

Equations 4 through 6 were similar to Equations 1 through 3 but were modified by empirical factors which took into account the amplification of ground motion in the presence of alluvium or similar type unconsolidated material. These factors, derived from the final analysis of Shoal measurements (Reference 3) were 2.1, 3.4 and 3.7 for acceleration, velocity, and displacement respectively.

A statistical analysis of the scatter in measured ground motions at Shoal showed that the value of one standard error of estimate was less than a factor of two for all components of acceleration, displacement

and velocity (Reference 3). Assuming normal distribution, about 68% of the measured values were within a factor of two of the statistical mean. It seemed reasonable to expect roughly the same scatter for the Longshot event. This meant that within the one standard error band the distances to significant motions could have shown the following variations:

for 0.1 g on hardrock - from 8 to 15 km

0.1 g on unconsolidated material -

from 11 to 23 km

0.001 g on hardrock - from 80 to 150 km

0.001 g on unconsolidated material -

from 110 to 230 km

2.3.2 Conclusions

Based on available information, the Longshot event appeared feasible from the point of view of peak ground motion. Graphs of predicted surface motions are presented in Figures 3 through 5. Predicted distance to 0.1 g and 0.001 g are shown on Figures 6 and 7, respectively, for locations on both hardrock and unconsolidated material.

The potential damage area (motions equal to or greater than 0.1 g) was predicted to extend to a distance of 11 km (6.9 miles) for structures on hardrock and 16 km (10 miles) where significant masses of unconsolidated material exists. The larger radius (16 km) covered

Figure 4. Predicted Peak Surface Particle Acceleration versus Radial Distance

Figure 5. Predicted Peak Surface Particle Displacement versus Radial Distance

Figure 6. Predicted Peak Surface Particle Velocity versus Radial Distance.

Figure 7 Map showing predicted distances to .1 g for points of interest on Hardrock and unconsolidated material.

Figure 8 Map showing predicted distances to .001 g for points of interest on hardrock and unconsolidated material.

only a portion of Amchitka Island. Since the island was uninhabited and totally government-owned, the possibility of damage to private facilities was of no concern. However, since fish and wildlife, including sea otter and migratory fowl, were prevalent on and about Amchitka Island and surrounding islands, ground motions may have been a consideration for agencies studying the biological effects of the Longshot event. Another similar hazard was the possibility of triggering earth slides and water waves. The closest shoreline was the Cyril Cove area at a distance of about one kilometer. Peak accelerations at this location were expected to be on the order of 10 to 20 g's.

Predicted distances to 0.001 g (Figure 7) were 110 km (69 miles) for hardrock surfaces and 160 km (100 miles) for areas with thick unconsolidated covers.

As 0.001 g was generally considered to be the limit of perceptibility, the largest expectable area of perceptible ground motion covered all of the Rat Islands and a few of the small islands at the western end of the Andreanof Islands. The closest settlement of permanent habitation was Adak, about 190 miles to the east. Therefore, the entire area of predicted perceptibility was probably uninhabited.

A significant qualification concerned the possibility of generating very long period surface waves. As no

adequate empirical data on this type of wave were available, their motions could not be predicted. Therefore, at long distances, particle motions, especially displacement, could possibly have exceeded those predicted.

CHAPTER 3

RESULTS AND CONCLUSIONS

3.1 GROUND MOTION

A limited evaluation of the predicted displacement values was possible by utilizing Reference 7. The only station reported in the publication within the prediction range was AD-IS on Adak Island, 291 km from the shot. The peak particle displacement for the LQ phase, which appears to be the maximum value, as recorded at the above station, gave a value of about 2.2×10^{-3} cm. Referring to Figure 5, on page 27, the above value falls just above the predicted line for points of interest on hardrock and well below for points of interest on unconsolidated material. Although one point is not conclusive by any means, it does indicate satisfactory predictions. In addition, no reports of excessive ground motion were received.

3.2 CONTAINMENT

On the basis of available information, Beers, Inc. considered the proposed site to be adequate, and stated that containment would be achieved for the Longshot

event. Containment was achieved as predicted. However, predicted values for parameters such as cracking radius, spalling, etc. could not be compared with the observed values since there have been no post-shot examinations.

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